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Psychological Monographs: General and Applied

Some Physiological Concomitants of Mental Work[1]

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I. ORIENTATION

THE PURPOSE of the present investigation is to study certain physiological responses in the light of three problems. (*a*) Do some physiological responses change significantly under conditions of light homogeneous mental work? And, if so, what is the nature of the changes? (*b*) Do the changes in some physiological responses show any degree of concomitance with the decrement in mental work production? (*c*) Are there any patterns of internal physiological responses related to mental work products, e.g., the mental work block?

In the statement of these problems certain terms must be defined. Physiological responses include those recordable visceral and peripheral responses of respiration, heart beat rate, blood pressure, level of skin conductance, and momentary changes in such conductance (GSR). Work involving successive discrimination of randomly and serially presented colors is regarded as light and homogeneous, because five color-naming (manual) responses were repeatedly called into play by only five different colors. The work of the task is called light to distinguish it from intense mental work, such as the mental multiplication of four-digit numbers by four-digit numbers.

Implied in the concept of mental work in this study is the understanding that mental work is the result of the activity of the total organism and not the mere "emission" of a few grams of brain cells, that energy is transformed and expended, and that changes in energy distribution occur within the "mental organ system" which alter the accomplishments of the individual. The results of this study support this understanding. It is foreign to good reasoning to assume that mental activity is produced without the use of energy.

Many of the errors of early studies of the relationship between mental activity and various physiological responses and energy measurements have been due to improper definition of the mental activity, faulty control, failure to recognize the relevance of momentary conditions of excitation, and incorrect presuppositions. The results of studies of total metabolic change during mental work are equivocal. Benedict and Benedict (2) obtained a 4 per cent increase in the use

[1] Based on a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at the University of Chicago, March, 1952.

This study, begun in 1937, grew out of a research program to determine some of the physiological correlates of the effects of mental work. The program was directed by Dr. Arthur G. Bills, now of the University of Cincinnati. Through his sponsorship and his kind, critical advice and encouragement Dr. Bills served to motivate and guide the eventual completion of the study. Much of the theoretical argument grew out of his work and writings. Later Dr. Austin H. Riesen assumed sponsorship of the thesis. Through his friendly counsel and critical examination of the study the degree of precision of the interpretation of some of the results was much enhanced. It is with sincere appreciation that the writer acknowledges the assistance granted him by both Dr. Bills and Dr. Riesen.

of O_2 during difficult mental multiplication. The increase was said to be due to the concomitant increase in circulatory and respiratory activity. This study is perhaps the most complete and precise of the many studies, yet it is not unequivocal in its findings and interpretation.

Implied in the conclusions of Benedict and Benedict and many of the previous investigators is the point of view of the purest of central theorists—namely, that from any recordable amount of total energy expended by a mentally active organism, one must subtract the energy due to any concomitant physiological process functioning in excess of the basal function. The futility of this point of view and methodology will be discussed later.

Permitting easier interpretation as a result of improved methods and analysis are the studies of Rounds, Schubert, and Poffenberger (25), Freeman and Giffin (17), and Darrow and Freeman (12), which certainly indicate the need for additional oxygen during mental activity. However, the work of Darrow and Freeman, and Freeman and Giffin clearly indicate the inadequacy of the total metabolic technique for the measurement of energy regimentation and transformation during mental activity or work. Freeman and Darrow (16) point out that metabolic activity in different parts of the body varies from time to time in the same individual under the same and varying conditions. An increase in activity in one organ system may be counteracted by a decrease in another organ and thus show a zero change in total metabolic measurement. Freeman and Giffin present a clear choice for those who work in the field of physiological reaction dynamics: total metabolic measurements through which neuromuscular activity is poorly reflected, or some more sensitive index such as the palmar skin conductance.

In the study of physical and mental work it is important that a reliable index of energy transformation be used. The work of Darrow and Freeman, and Freeman and Giffin has established the high reliability of skin conductance measurements as an index of neuromuscular reactivity and its relationship to oxygen consumption. The positive relationship between skin conductance changes and tonus changes has been well established (18). Sears (28) and Kirby (23) noted that skin conductance level varied concomitantly with changes in mental work.

The work of Schubert (27) and others has shown that cardiac activity is an excellent index of energy transformation, that such activity is directly related to oxygen consumption.

Those who recorded respiratory changes with total metabolic rate changes during mental work (25, 27) obtained increases in respiration rate from the mental work. Since respiration changes are subject to voluntary control, their measurement is less reliable as an indicator of energy requirements than pulse rate measurements. Other studies have shown the relationship between respiration and different behavioral states; e.g., startle, expectancy, mental work, and rest (22, 29).

A relationship between blood pressure changes and total metabolic rate changes has not been established (26). However, studies have shown a relationship between blood pressure changes and neuromuscular reactivity (14, 21). The organism is provided with equilibratory mechanisms between the vascular and the neuromuscular systems through the autonomic system (20).

The present investigation is designed to take advantage of the more recent conclusions concerning the relationship between certain secondary physiological responses and total metabolism, and to use such physiological responses as indices of energy transformation and neuromuscular reactivity. Most of the older studies failed to make use of simple statistical techniques for the evaluation of obtained means and differences; the present study is designed to apply such techniques.[2]

[2] Critical ratios were obtained by the use of the standard error of the difference formula 26a in McNemar, Q. *Psychological statistics.* New York: Wiley, 1949. P. 65.

II. METHOD AND PROCEDURE

A. Subjects

Ten male college-student (upper division and graduate) subjects were able to complete either all of the experimental program or a sufficient amount to be used in the study. Fifteen subjects started the program but five could not finish for a variety of good reasons, such as insufficient time, working schedule change, obtaining of other employment, etc.

B. The Mental Work Task

The mental work task was color naming. The colors—red, yellow, green, blue, and white—were presented serially and in random order by means of a Bills' psychergometer (6). The colors were painted on a continuous, 35-mm. steel film strip. The strip contained 250 color stripes, 3/8 of an inch wide. Each color appeared in a well-lighted window and was magnified by a lens which doubled the color area. The subjects discriminated each color by manually responding to a set of correspondingly colored keys. Pressing a key automatically presented the next color. The task was to learn to respond to the perceived color by pressing the corresponding colored key as fast as skill and motivation permitted.

Each subject was practiced in responding to the colors to the point where his progress seemed to stabilize before being introduced to the experimental conditions. Each had four to seven practice sessions of a half-hour or more. Some attained a speed of about one hundred colors per minute; others were able to respond to only sixty colors per minute after the practice period. The average rate during the first five minutes of work (after the practice series) for all subjects and all days was 90.5 color discriminations per minute. It was planned that the color-naming skill become sufficiently stabilized in practice that learning effects would not counterbalance continuous work effects.

The incidence and reaction time of each color discrimination were photographically recorded.

C. The Experimental Program

The following general program was planned for each subject after color-naming proficiency had been attained and after each subject had adjusted and become used to the apparatus and the laboratory situation: Day 1, mental work; Day 2, motor work; Day 3, mental work; Day 4, motor work; Day 5, sensory work; Day 6, mental work; Day 7, sensory work; Days 8 and 9, mental work under anoxia; and Day 10, mental work. Each of these experimental days consisted of recorded periods of ten minutes of prework rest, 55 minutes of work, and ten minutes of postwork rest. These rest period records will be referred to as *prerest* and *postrest*, respectively.

On the mental work days (MW condition) each subject was instructed to work as fast and accurately as he could. The mental work under anoxia will not be reported here.

The motor work period was intended as a period for the exercise of the "motor component" of the color-naming discrimination mechanism. Each subject was blindfolded and instructed to operate the keyboard keys at a rate estimated to be equal to his actual color-naming rate. The subject's keyboard responses were the only indication of the fulfillment of the condition task. This condition will be referred to as MC (for "motor component").

The sensory work period was intended as a period for the exercise of the "sensory component" of the color discrimination mechanism. The colors were presented at a set rate of 90 colors per minute. Each subject was instructed to "sense the colors passively." The subject's visual regard was used as the indication of fulfillment of the task. This condition will be referred to as SC.

Control days consisted of a 55- or 60-minute period of "rest." The subjects were told to assume a state of mental re-

pose, to close their eyes and rest without sleeping if they could avoid sleep. This was difficult to do since they were semi-reclined in the specially made tilted chair with a back which angled 110° from the seat, and were provided with a leg rest so that the ankle was at the same level as the heart. The chair was well cushioned and the head was supported. The room was quiet except for the operation of the apparatus. Sleep was natural in this condition, so care was taken not to tell the subjects they were forbidden to sleep since such instruction would produce too great an effort to stay awake and disturb the record too much. The SC condition was also sleep-inducing to most of the subjects. The constant passive (glazy-looking attitude) "sensing" of the colors was difficult for the subjects and served to induce sleep or mere rest with eyes open. For some subjects the SC condition was a better control condition than the intended control condition.

The experimental program served more as a plan of work than as a dictated schedule to be followed. Deviations from it were not more than 25 per cent. The mental work days were spaced at least two calendar days apart. In only a few cases were experimental sessions actually scheduled on consecutive calendar days. Most of the experimental sessions were spaced two calendar days apart. Since there was such spacing between sessions and since there was no evidence of transfer of work effects evident in the mental work records, minor changes in the scheduling of days from subject to subject were regarded as not seriously jeopardizing the precision of the results. Whether attitudinal fatigue effects were transferred from session to session is not known. The only alteration in the schedule of sessions was in the occasional shift in the order of sensory and motor work days and the introduction of control sessions. Some of the subjects failed to meet the requirements of the control rest condition, even after four or five attempts and the completion of the experimental sessions. For these subjects the sensory work records were substituted for control days. It may be noted that Benedict and Benedict (2) regarded their attention and control rest conditions as equally basal. At least two *control records* were used for each subject. The records were obtained from nonscheduled sessions at the convenience of the experimenter and as laboratory conditions dictated.

All ten subjects completed, and were included in, the MW determinations—40 MW days in all.

Nine subjects made up the MC condition determinations; one subject, Le, was not included in the determinations because certain key-tapping sequences would habitually initiate in him a melodic time pattern in tapping as though he were playing the piano. The variations in tapping time disturbed his record too much. Thus there were only 18 days, instead of the planned 20, of the motor component condition.

Six subjects made up the determinations of the SC condition. One subject regularly fell asleep during this condi tion. Three subjects could not fulfill the control condition requirement of mental repose; their SC condition records were used as control records. Thus there were only 12 days of SC condition records.

All ten subjects were included in the control condition determinations (counting the SC condition substitutions). Two subjects had three days of control. Thus there were 22 days of control condition records.

D. Rationalization of Experimental Conditions

The rationale for use of the motor work (MC) and sensory work (SC) conditions grows out of historical necessity and interpretation. Therefore, it is necessary to make clear some of the assumptions that were in operation during the study. (*a*) The MC and SC conditions have been introduced to satisfy the central theorists. However, it is not claimed that the tenableness of the centralists' position can be demonstrated by this

study. (*b*) The conditions of MC and SC are not "pure" conditions. Both sensory and motor activity are present in the MC and SC condition behavior. Though patterned differently, the activities overlap and hence cannot be "subtracted out" from behavior and physiological activity of the MW condition.

The MC and SC conditions are artificial and cannot lead to any conclusion concerning the centralist hypothesis.

In the treatment of results, however, the procedure of adding or subtracting the changes in the MC and SC conditions from the changes produced in the MW condition was carried through to satisfy the erroneous presuppositions of the central theorists. But the best interpretation that can be made of the changes that occur during the MC and SC conditions is one which regards the changes as being associated with different degrees of mental activity, different in degree of difficulty from that mental activity involved in the MW condition. Such an interpretation may be logically made from a central-peripheral theory of mental activity. Conclusions regarding a relationship between mental work and certain implicit physiological activity must be drawn from a comparison between the mental work period of Days 1, 3, 6, and 10 and the control days, and between the pre- and post*rest* periods and the *work* periods of each day. These changes are described both as absolute and as relative (percentage) changes from the control days level and from the pre- and postrest level.

E. The Implicit Physiological Activities Measured

Heart beat rate, respiration rate, relative blood pressure change and level, volumetric change of the index finger, skin conductance level, and incidence of magnitude of galvanic skin responses were recorded and measured for all subjects during all conditions.

These activities were photographically recorded by means of the Behavior Research photopolygraph (9) originally designed by Dr. C. W. Darrow. Detailed description of the techniques of recording these responses and the shortcomings of each may be obtained from the dissertation (19).

Because of the expense of the bromide paper rolls, records were made only of the ten minutes of prerest and the ten minutes of postrest for all conditions, and the alternate five minutes of the work periods of each condition. The periods of record were minutes 1-5, 11-15, 21-25, 31-35, 41-45, and 51-55, six 5-minute periods for each work period for each condition.

Since it was anticipated on the basis of preliminary research that the duration of many of the changes in the several implicit physiological activities would be shortlived when they occur during a mental work period—presumably stimulated by various mental work changes—a short time unit should be used for all measurements of these activities. Fifteen seconds were deemed sufficient in duration to reflect most of the changes. The levels and changes in levels of activity of all recorded responses were measured for each 15 seconds during all recording periods.

III. RESULTS: PRESENTATION, TREATMENT, AND INTERPRETATION

Before presenting the data obtained from the measurement of the various physiological responses and noting whether some of the implicit physiological activities change significantly under conditions of light homogeneous mental work, the results of the mental work performance—manual color naming for 55 minutes—will be considered.

The mean number and the standard error of the mean of responses per 15 seconds for each of the 6 alternate 5-

minute work record periods, of the combined four mental work days (Days 1, 3, 6, and 10), for each of the 10 subjects and for the group were obtained. Each mean for each subject is based upon about 80 measurements (four 15-seconds in a minute, times 5 minutes, times 4 days), the exact number diminished slightly only by record faults.

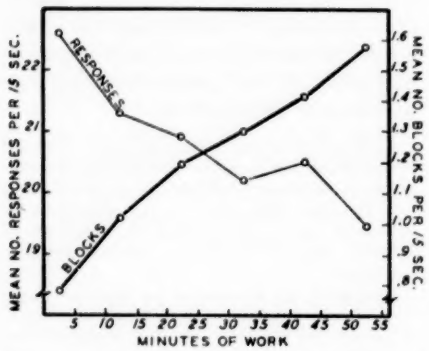

FIG. 1. Color-naming Work Curve in Terms of Average Number of Responses and Blocks per 15 Seconds for Each 5-Minute Record.

Figure 1 is a plot of the group means and describes the production trend in the color-naming performance of the 10 subjects in terms of the mean number of responses per 15 seconds for each recorded 5-minute period for the 55 minutes of mental work. As already noted, all subjects were practiced in the color-naming task.

The 55 minutes of manual color naming resulted in a decrease in each subject's rate. The decrement obtained in color-naming production is characteristic of this length of work; the production in the last five minutes was 14 per cent less than in the first five minutes. The decrease in color-naming discrimination rate is not great. In terms of number of responses per unit of time, little seemed to be lost in work rate. But it must be added that all subjects reported distinct distaste for and discomfort from the task. They were, as they claimed, tired at the end of each session. Each subject appraised the task and situation as monotonous, though none claimed to be bored. The semireclined and harnessed position may account for some of the subjects' attitude and general behavior, since it was necessary to maintain a rather fixed position to insure stable recording of the various physiological responses.

No direct measurement was made of the reaction time of each response. However, occasional indirect measurements were made by subtracting the number of blocks and total block time, and then dividing the number of nonblock responses into the total nonblock response time. There was no noticeable increase in reaction time in the regular responses. Bills (3) noted that the average reaction time of nonblock responses in color naming is fairly constant throughout an hour of work. The toll of the effect of the continuous homogeneous mental work of color naming is reflected in the increased incidence of blocks as defined by Bills (3).

The mean number and standard error of the mean of blocks per 15 seconds per 5 minutes for each of the recorded 5-minute periods, for the combined 4 days of mental work, for each subject, and for all the subjects were obtained. Again, each mean for each subject for each record period was based upon about 80 measurements. Figure 1 also provides a plot of the group means and describes the trend of increasing incidence of blocks for the 10 subjects throughout the 55 minutes of work. There are almost 100 per cent more blocks per unit of time in the last 5 minutes than in the first 5 minutes. This is characteristic of the effect of continuous simple homogeneous mental work.

The question as to whether the trend

in the response curve and the block curve is significant can be answered by an analysis of the differences between the parts of the curve. The two curves were divided into three parts; record periods 1-5 minutes and 11-15 minutes, 21-25 and 31-35, and 41-45 and 51-55 minutes respectively were combined and tested as to reliability of difference between the successive thirds and the direction of the trend. All critical ratio tests (m_{diff}/SE_{diff}) assure a better than 1 per cent confidence, except the test for the difference between the second and third thirds of the response curve. We must conclude that the possibility of chance alone determining the changes in the rates of color naming and blocking during the course of an hour of work is quite remote. The changes are due to causes found in the work operation and the organization of the responding subject. These changes receive greater meaning when noted in their relationship to some of the changes in physiological responses.

Bills (4, 5) has noted that the chief causes for blocking are the repeated excitation of the same response mechanism (the principle of homogeneity) and the tendency for different though similar response mechanisms to compete for the common efferent pathway (the principle of competition in mental work), thus resulting in faltering response in the task of color naming. The fewer the colors to respond to, the more often a response mechanism will be called into play and the greater the blocking; the more colors there are to respond to, the greater will be the competition of response outlet to a given color, and the greater will be the resulting blocking. The latter principle probably accounts for most of the decrement (4).

The question may be asked, is fatigue generated during the mental work? In terms of the work decrement of color-naming responses and the increment of blocks, we can only infer the presence of fatigue. It is generally maintained that mental fatigue is objectively reflected in its effect upon output by diminishing response rate and by the increasing momentary faltering (blocks) of the response mechanism. While this may be quite so, it does not follow that the generation of fatigue is in a one-to-one relation to the development of the product decrement. That the subjects were fatigued was evident to them. They all reported fatigue but made a distinction between fatigue and boredom. They were relieved to be finished and released from the apparatus. They all reported that their feelings did not terminate when they were finished and released. They all stretched and yawned at the end of each session. No systematic study of fatigue feelings was made. Where fatigue feelings are reported as evidence in this study, it should be recognized as evidence obtained through unsolicited fragmentary comments made by the subjects and inference from behavior occurring during and after experimental sessions. While we agree with Bartley and Chute (1) that fatigue is largely attitudinal and a function of emerging disorganization in the total individual, the implication that fatigue is so superfunctional as to be epiorganic is not accepted. Mental fatigue may be reflected in the attitudinal response of the mental worker, as well as in the disorganizational consequences of work output and the organic state.

A. Respiration

The rate of respiration will be examined first to determine if there exists a significant change as a result of mental work. Group data only will be considered in the study of this problem. The data of the individual subjects were treated in the same way as the group results and do not differ essentially. For all physio-

TABLE 1

MEAN (m) AND SE_m OF RESPIRATIONS PER 15 SECONDS FOR EACH RECORD PERIOD OF THE EXPERIMENTAL AND CONTROL CONDITIONS

Condition	Prerest 10 min.	Work Period 55 Minutes						Postrest 10 min.	Total Work	Total Rest
		1–5	11–15	21–25	31–35	41–45	51–55			
MW										
m	4.27	5.08	4.76	4.69	4.60	4.51	4.52	3.87	4.69	4.08
SE_m	.025	.046	.044	.042	.044	.048	.045	.024	.018	.018
MC										
m	4.25	4.79	4.55	4.50	4.44	4.54	4.39	3.99	4.54	4.13
SE_m	.036	.048	.051	.043	.047	.050	.051	.034	.020	.026
SC										
m	3.80	4.30	4.06	3.96	3.92	3.95	3.87	3.64	4.02	3.73
SE_m	.037	.057	.061	.064	.071	.065	.068	.039	.027	.027
Control										
m		4.13	4.00	4.07	3.90	3.91	3.88		3.98	
SE_m		.052	.044	.040	.041	.045	.045		.018	

logical records, the number of measurements for each subject for a complete day's record for the MW, MC, and SC conditions would be 40 for prerest, 120 for all six five-minute record periods, and 40 for the postrest period. Record faults and miscalculations in timing record periods diminish these numbers.

Table 1 presents the mean number and the standard error of the mean of respirations per 15 seconds for each record period of the experimental conditions of MW, MC, SC, and control for the combined days of similar conditions.

To illustrate the trend in respiration rate change during the work periods of the MW, MC, and SC, and control rest, plots of the averages are presented in Fig. 2.

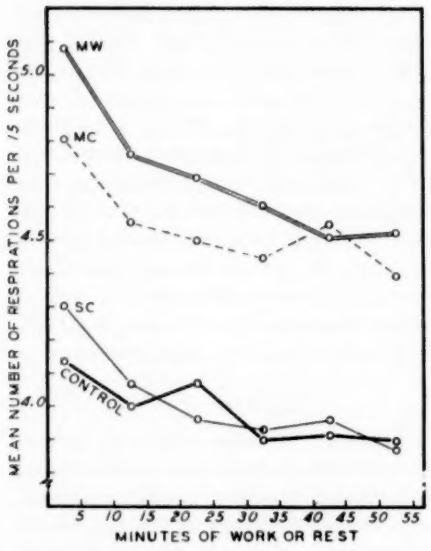

FIG. 2. Trends in Average Rate of Respiration per 15 Seconds for Successive Record Periods during MW, MC, SC Work, and the Control Rest Conditions.

The curves of respiration rate change decrease for all conditions. The similarity between the control and sensory component (SC) curves is apparent. Both the MW and MC condition curves appear distinct from the control curve. The MW curve has the greatest decrement. The changes indicate a respiratory adjustment to the situation during the work and control periods. This adjustment during MW is such that respiration rate becomes less as color-naming output becomes less, and block incidence becomes greater. The decrease in respiration rate is not accompanied by an increase in respiration depth (determined by inspection), nor a decrease in the inspiration

fraction. If depth increased there would be compensation for the rate decrease; likewise, if I-fraction decreased there would be an indication that the inspired air was retained longer and thus made available more oxygen absorption. But on the basis of casual examination (not reported) of all mental work records, neither of these effects occurred to compensate for the rate decrease during the 55 minutes of mental work. Note that the greatest decrease in respiration rate for all curves is during the first 15 minutes.

The SC and control curves are essentially identical in the second half. The initial high rate of respiration is a part of the behavioral mobilization and realignment to the particular task at hand. The physiological demand is greatest during the mental work task of color naming. The initial high rate of respiration during the SC condition is probably due to the abrupt need to adjust and attend to the passing colors from a level of adjustment of a sleep or quasi-sleep state. At no time during the control record periods did the average rate of respiration descend to the average rate obtained in the pre- and postrest periods of the SC condition (Table 1).

The critical ratio tests of significance of the differences between the average number of respirations per fifteen seconds during the work and during the rest periods within the same experimental condition are indicated in Table 2. All respiration rates during the work periods of the MW, MC, and SC conditions are significantly greater than the respiration rates during the prework and postwork rest periods of their respective experimental condition. For all conditions the prerest respiration rate is higher than the postrest respiration rate (see Table 1). The higher prerest respiration rate is probably due to the preparation set of the subject for the anticipated work. The lower rate of respiration during the postrest periods is the result of the release from the mobilized demands of the task. There does not seem to be any delayed payment of energy debt for the continuous work, whether it be color-naming, key-tapping, or color-sensing work, for the rate of respiration drops abruptly within the first minute of postrest and gradually continues to drop further. The resulting average rate of respiration for the postrest periods is either equal to or less than the average rate during the control rest condition (see Table 1). The tests of significance permit the conclusion that manual response color naming (MW), keyboard tapping at a self-determined rate (MC), and mere gazing at serially presented colors (SC) result in higher respiration rates than obtained during ten-minute rest periods before and after the work period.

TABLE 2

CR TESTS OF SIGNIFICANCE OF DIFFERENCE BETWEEN THE REST PERIODS AND THE WORK PERIOD WITHIN EACH EXPERIMENTAL CONDITION FOR RESPIRATION RATE

Rest Period	Work Period of Condition*		
	MW	MC	SC
Prerest	13.7	6.85	4.82
Postrest	27.3	13.8	7.87
Total rest	24.0	12.5	7.62

* Differences are in favor of the work periods.

The respiration rates for the work periods of MW, MC, and SC conditions are all significantly different. Color-naming work demanded a greater rate of respiration than mere keyboard tapping, and this, in turn, demanded more than mere sensing of the presented colors.

The tests of significance between the

control condition and the experimental conditions are shown in Table 3. All of these differences are diagrammatically represented in Fig. 3, where the average rate of respiration during the control condition serves as the base line from which are projected the absolute differences in the rate of respiration of all work and postrest period conditions. The first five-minute period of control rest was used in noting differences between the prerest period of the experimental conditions and control because of its temporal comparability. The absolute differences between the 55-minute work periods of MW, MC, and SC, and control are translated into percentages and noted on top of the respective bars in Fig. 3.

The SC condition exacted only a .7 per cent increase in respiration rate over the control rest base. The pre- and postrest of the SC condition appear to be a challenge to the legitimacy of the control rest base line. Noted are the inversions; the average respiration rate is less during pre- and postrest than during control rest. If the true control rest base line were lower, it would be in favor of greater differences between it and the other conditions. But the sensory component condition is unique in its effect upon subjects. One subject, Da, could not abide by the instruction to passively observe the colors, and promptly fell asleep. Three attempts were made to get an SC condition from him. His records could not be used. All the other subjects complained of the difficulty of staying awake. The difficulty was discussed with each subject and all attempted to abide by the instructions to passively observe the colors, to maintain a fairly alert attitude, but not to fight off sleep if it overcame them, for such an effort would disturb the record. If the subject slept, the record was not used. Thus some of the subjects took advantage of the prerest condition and usually got a short nap during that period (though this was undesirable as far as the experiment was concerned it seemed to be a needed toleration), and when the postrest period came, again fell asleep. The other subjects closed their eyes and deeply relaxed during these periods. This accounts for

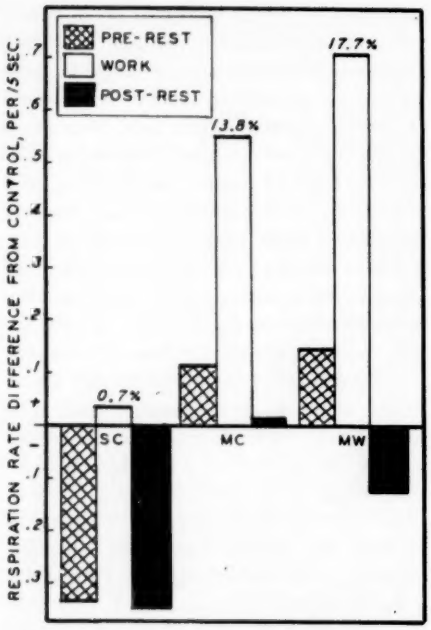

FIG. 3. Differences between the Average Respiration Rates of Control and the SC, MC, and MW Work Conditions, and between Control and Other Rest Periods.

TABLE 3

MEAN$_{diff.}$, $SE_{diff.}$, AND CR TESTS OF SIGNIFICANCE OF DIFFERENCE BETWEEN THE CONTROL CONDITION AND EACH PERIOD OF EACH EXPERIMENTAL CONDITION FOR RESPIRATION RATE

Period	CR Test between Control and Experimental Condition		
	MW	MC	SC
Prerest			
$M_{diff.}$	.142	.121	.333*
$SE_{diff.}$	.058	.064	.064
CR	2.45	1.88	5.20
Postrest			
$M_{diff.}$	.127*	.005	.341*
$SE_{diff.}$	.030	.040	.043
CR	4.19	.13	7.92
Total rest			
$M_{diff.}$	.096	.14	.258*
$SE_{diff.}$	.026	.032	.032
CR	3.77	4.42	7.95
Work			
$M_{diff.}$	.709	.551	.030
$SE_{diff.}$	.026	.027	.010
CR	26.3	20.21	2.94

* Difference is in favor of the Control condition.

TABLE 4

MEAN (m) AND SE_m OF HEART BEATS PER 15 SECONDS FOR EACH RECORD PERIOD OF THE EXPERIMENTAL AND CONTROL CONDITIONS

Condition	Prerest 10 min.	Work Period 55 Minutes						Postrest 10 min.	Total Work	Total Rest
		1–5	11–15	21–25	31–35	41–45	51–55			
MW										
m	17.363	18.891	18.685	18.745	18.389	18.449	18.160	15.965	18.555	16.71
SE_m	.057	.077	.081	.087	.086	.089	.091	.057	.035	.042
MC										
m	16.811	17.017	16.615	16.456	16.428	16.452	16.387	15.682	16.563	16.264
SE_m	.094	.129	.137	.127	.116	.133	.126	.091	.052	.067
SC										
m	17.299	17.225	17.129	16.773	17.085	16.877	17.062	15.284	17.025	16.296
SE_m	.096	.124	.145	.135	.149	.143	.149	.082	.065	.071
Control										
m		16.984	16.294	16.12	16.227	15.726	15.61		16.089	
SE_m		.124	.115	.114	.109	.116	.112		.048	

the lower rate of respiration during these periods as compared with the control rest base line.

The desired attitude for the control rest condition was an attitude of mental repose, a state of wakefulness, but complete relaxation and as much freedom from mental activity as possible. This was a difficult adjustment to maintain by any alert student during the course of a school day. Perhaps it is an impossible adjustment to make! Three of the subjects encountered some difficulty in meeting the control condition requirements. One subject, Gi, fell asleep during the control rest day but was able to stay awake during the SC condition by virtue of the limited stimulation of the recurring colors. Two of the subjects, Ro and Wh, were of the "keep-busy" sort and were bored by the control rest situation and stimulated by tendencies and ideas that kept them fairly excited. They moved about too much and seemed to want to get it over with, feeling they could be doing something worth while. These three subjects had their so-called control rest day records discarded. The "work" period of the sensory component days was substituted for the control rest days. Thus, although all ten subjects make up the control group results, only six of the ten subjects make up the SC condition group results.

The inversion in the postrest following mental work is understandable. All subjects closed their eyes and deeply relaxed after the tiring 55 minutes of color naming: subjects Da, Me, Gi, and To usually slept.

The motor component condition (MC) resulted in a 13.8 per cent increase in average rate of respiration, while the mental work of color naming resulted in a 17.7 per cent increase. The tests of significance of difference (Table 3) between control rest and MW, MC, and SC work periods permit the conclusion that the rate of respiration of the experimental conditions is reliably greater than the control rest rate of respiration.

B. Heart Beat

Table 4 presents the mean number and the standard error of the mean of heart beats per 15 seconds for each record period of the experimental conditions and of the control rest condition. These averages are the result of the combination of similar condition days and are for the group.

The six five-minute record periods for all conditions are plotted in Fig. 4 to illustrate the trend of change in average heart beat per unit time during the work periods of the experimental conditions and the control rest condition. The MW curve is notably distinct from the other curves. The trends of the MW, MC, and SC curves are similar, each tending in the direction of a reduction in heart beat rate as work progresses. The decrement in the control rest curve is greater than the curves of the experimental conditions. Using the method of testing reliability of difference between successive thirds of the curve, the decrement seems not to be due to chance (better than 1 per cent). The test of trend differences indicates that the decrease in the heart beat rate is due to factors inherent in the work

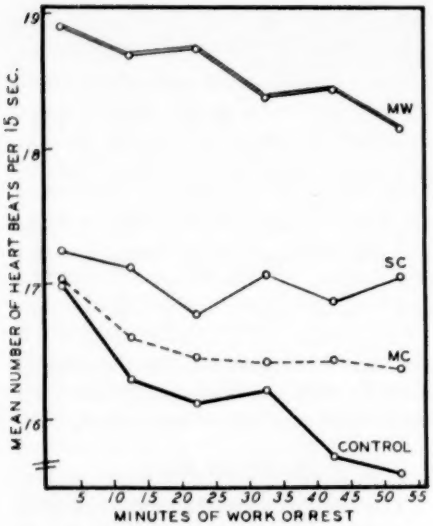

FIG. 4. Trends in Average Rate of Heart Beats per 15 Seconds for Successive Record Periods during MW, SC, MC, and Control Conditions.

tasks and operations and probably represents some progressive adjustment to the situation. The exact nature of the adjustment is a question. In the case of the SC condition, the high heart beat rate probably indicates a greater cardiac demand during this condition than during MC. The SC condition demanded a higher degree of attention for its continuance if the subjects were successful in preventing sleep than did the MC condition. The difference between the MC and SC conditions is reliable, but the difference may be due to selection. It must be remembered that the SC "population" consisted of six subjects, the MC of nine subjects. Three of the subjects who had their SC days transferred to control days were slow in their heart rate as compared to the average; one subject was a little faster. Had their records been included in the SC condition, they would tend to lower the SC condition averages.

The significance of the difference between the mean number of heart beats per 15 seconds during the work and during the rest periods within the same experimental condition is indicated in Table 5. The heart beat rate during the work period of the MW condition is quite significantly different from the rest rates before and after the mental work of color naming. All the postrest heart beat rates for all work conditions—MW, MC, and SC—are reliably less than their respective work rates; in fact, the postrest heart rates are lower than the heart beat rate during the control rest condition. But the prerest heart beat rates for the MC and SC conditions are reliably higher than the average rate during their respective work periods. Each rate during the prerest periods must be evaluated in terms of the anticipated task. It should be noted that although the MC and SC prerest heart beat rates were higher than the work rates of the same condition, the rates were lower than the prerest rate for the MW condition. None of the prerest rates was as low as the control rest condition rate (Table 4).

TABLE 5

CR TESTS OF SIGNIFICANCE OF DIFFERENCE BETWEEN THE REST PERIODS AND THE WORK PERIOD WITHIN EACH EXPERIMENTAL CONDITION FOR HEART BEAT RATE

Rest Period	Work Period of Condition		
	MW	MC	SC
Prerest	17.8	2.31*	2.38*
Postrest	38.9	8.47	16.73
Total rest	33.7	3.52	7.59

* Difference is in favor of the rest period.

Using the average heart beat rates of the total-rest periods as the base line for judgment, the conclusion is certainly permitted that color naming (MW), tapping of the keyboard (MC), and mere

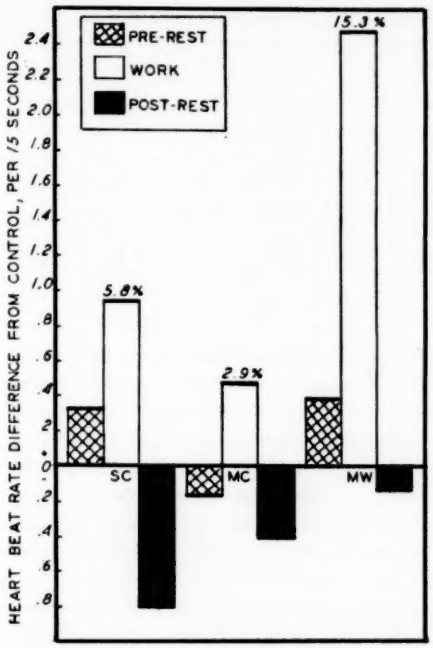

FIG. 5. Differences between the Average Heart Beat Rates of Control and the SC, MC, and MW Work, and between Control and Other Rest Periods.

looking at serially presented colors (SC) result in average heart beat rates reliably greater than the average rate obtained for rest periods during the same experimental work day setting.

The tests of significance of difference between the control condition heart beat rate and the various work and rest period rates of the experimental conditions are shown in Table 6. All of the differences listed in Table 6 are illustrated in Fig. 5 by the use of a bar diagram. The absolute differences are obtained from the base line of the average heart beat rate of total control rest for the work and postrest periods, while the prerest differences are obtained from the base line of the average of the first five minutes of control rest. The base line of these differences must be remembered when comparing the direction of differences between rest periods of different conditions in Table 6.

TABLE 6

MEAN$_{diff.}$, $SE_{diff.}$, AND CR TESTS OF SIGNIFICANCE OF DIFFERENCE BETWEEN THE CONTROL CONDITION AND EACH PERIOD OF EACH EXPERIMENTAL CONDITION FOR HEART BEAT RATE

Period	CR Test between Control and Experimental Condition		
	MW	MC	SC
Prerest			
$M_{diff.}$	.379	.173*	.315
$SE_{diff.}$	.136	.155	.156
CR	2.78	1.11	2.01
Postrest			
$M_{diff.}$	.124*	.407*	.805*
$SE_{diff.}$	.074	.102	.095
CR	1.67	3.98	8.46
Total rest			
$M_{diff.}$	.631	.176	.206
$SE_{diff.}$	.064	.082	.086
CR	9.88	2.13	2.40
Work			
$M_{diff.}$	2.466	.474	.936
$SE_{diff.}$	.059	.071	.080
CR	41.5	6.69	11.7

* Difference is in favor of the control condition.

C. RELATIVE BLOOD PRESSURE

The physiologic response record most difficult to obtain and maintain was the trace of relative blood pressure change.

Each measurement of BP trace level was made from an arbitrary "zero"—90 millimeters on a millimeter scale—at the beginning of each five-minute record period and at the beginning of the first and sixth minutes of pre- and postrest. Thus, an average value for such a record period is a statement of the level to which the record trace descended or ascended on the average from the initial level of 90 millimeters on the scale used to measure the displacement of the trace on the record.

The treatment of these measurements

TABLE 7

MEAN (m) AND SE_m OF MEASUREMENTS OF DISPLACEMENT OF LEVEL OF BLOOD PRESSURE PER 15 SECONDS FOR EACH RECORD PERIOD OF THE EXPERIMENTAL AND CONTROL CONDITIONS

Condition	Prerest 10 min.	Work Period 55 Minutes						Postrest 10 min.	Total Work	Total Rest
		1–5	11–15	21–25	31–35	41–45	51–55			
MW										
m	86.860	90.523	90.611	89.435	92.00	90.867	92.272	89.775	90.951	88.239
SE_m	.253	.245	.310	.336	.338	.350	.549	.224	.156	.152
MC										
m	86.953	88.469	89.266	88.028	90.828	89.807	90.852	87.388	89.523	87.164
SE_m	.273	.301	.484	.332	.506	.352	.416	.283	.169	.245
SC										
m	87.448	86.417	90.021	89.269	90.194	90.614	89.857	89.076	89.383	88.211
SE_m	.297	.403	.539	.366	.373	.603	.315	.313	.189	.218
Control										
m		86.575	86.423	86.494	88.563	88.329	85.676		87.002	
SE_m		.353	.276	.314	.303	.369	.333		.135	

will provide an adequate statement of the average amount of displacement of BP level from condition to condition and between successive five-minute work record periods, or rest periods, within a condition, if it is assumed that errors of measurement are approximately equal in all periods compared. The BP measurements were treated in the same manner as the respiration and heart beat rate changes.

Table 7 presents the mean and SE_m of displacements of level of BP trace per 15 seconds for each of the record periods for each experimental condition and for control. The data are the result of combining similar condition days.

Since the changes in actual blood pressure are continuous and the direction of change is relative to the previous moment's level and excitation background, the data presented in Table 7 may be translated into a form which will picture the progress of pressure change and direction. This is done in Fig. 6 with certain assumptions. One may assume that the various measured displacements in BP trace are not only representative of blood pressure change in the record periods themselves, but also representative of blood pressure changes in adjacent unrecorded periods. Furthermore, changes that do occur at one moment become conditions that partly determine the changes in the next moment. Thus if the *differences* between the base measurement of 90 made at the beginning of each 5 minutes and the average displaced level recorded for each 5 minutes are cumulated, one may plot these cumulations and thereby gain some idea of the

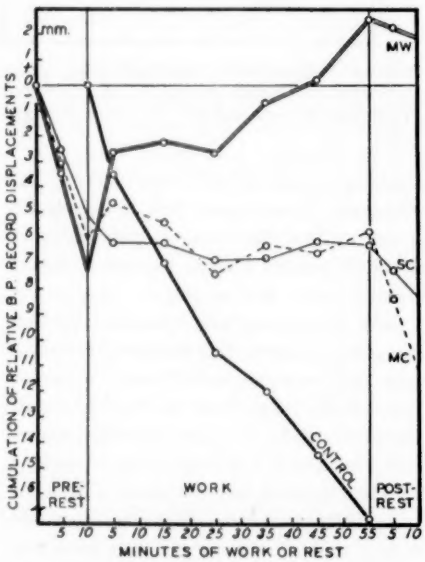

FIG. 6. Cumulation of Average Displacements of Changing Level of Relative Blood Pressure for Each Successive Record Period during the Prerest, Work, and Postrest Periods of MW, MC, and SC Conditions and during Control.

continuous change of the BP trace. The curves in Fig. 6 are not to be regarded as accurate descriptions of either relative changes in blood pressure or actual changes in the record trace of relative blood pressure. The cumulations are from averages of displacements in BP trace, not from levels of traces at the very last moment of a record period, and certainly not from that level of pressure at the very moment (an unrecorded moment) just before a record period.

The control condition resulted in the greatest change in BP trace displacement. The curve shows a rather abrupt drop in pressure during the first half of the period and lessening in the amount of decrease as the hour continues. The considerable decrease in pressure that occurred at the very end of the rest period is probably due to sleep, or to impending sleep. The changes in pressure during control are "smoother" than in the other conditions.

Figure 6 shows each curve beginning at the arbitrary "zero" value of 90. The points of the curves for the work conditions and the control condition are plotted at the end of each record period on the basis of the assumptions made. This makes for less distortion in the curve. The plots for the pre- and postrest periods of the experimental work conditions are made in the middle of these periods. The plot points for the pre- and postrest periods are the average of the BP trace displacements of that rest period. In interpreting the curves of the changes during and from prerest to the work periods in the MW, MC, and SC conditions, one is aided by examining the individual polygraph records of the changes in relative pressure. This examination reveals that the curves in Fig. 6 describe in general the course of pressure changes as they actually were recorded. During the MC and SC conditions, the pressure decreases and tends to continue so through the prerest into the work periods. During the mental work condition, relative blood pressure actually increases markedly with the onset of mental work from the decreasing lower level which occurs during the MW prerest period.

On the basis of our attempts to approximate the actual pressure change represented by the relative blood pressure trace changes, it may be conservatively estimated that the repose permitted in the control condition results in a progressive diastolic pressure decrease to about 15 mm. of Hg at the end of the rest hour. Color naming by means of manual response results in a gradual increase in diastolic pressure amounting to about 8 mm. of Hg at the end of the work hour.

TABLE 8

MEAN$_{diff.}$, $SE_{diff.}$, AND CR TESTS OF SIGNIFICANCE OF DIFFERENCE BETWEEN THE CONTROL CONDITION AND EACH PERIOD OF EACH EXPERIMENTAL CONDITION FOR DISPLACEMENT OF RELATIVE BLOOD PRESSURE TRACE*

Period	CR Test between Control and Experimental Condition		
	MW	MC	SC
Prerest			
$M_{diff.}$	.285	.378	.873
$SE_{diff.}$	.434	.446	.461
CR	.655	.846	1.89
Postrest			
$M_{diff.}$	2.773	.386	2.074
$SE_{diff.}$	.261	.264	.340
CR	10.62	1.46	6.09
Total rest			
$M_{diff.}$	1.237	.161	1.209
$SE_{diff.}$	.203	.224	.256
CR	6.09	.720	4.72
Work			
M_{diff}	3.949	2.521	2.381
$SE_{diff.}$	.206	.216	.232
CR	19.41	11.66	10.26

* All differences are in favor of the experimental conditions.

Table 8 presents the critical ratio tests of significance of difference between the control rest condition and each period of each experimental condition for the average level of BP trace. All of the differences tabulated in Table 8 are illustrated by means of a bar diagram in Fig 7. All the work period (total work) averages of the BP trace level are quite significantly higher than the average BP trace level during control rest. The pre-

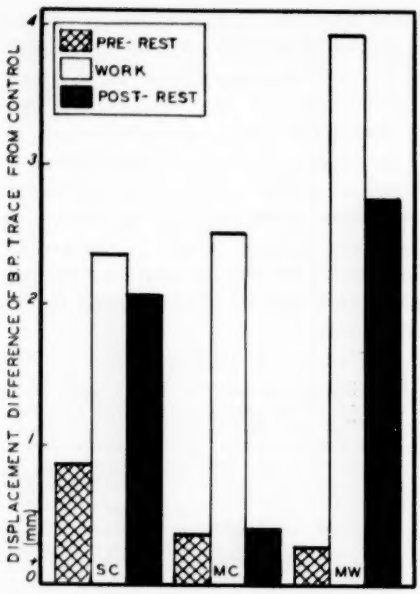

FIG. 7. Differences between the Averages of the Relative Blood Pressure Trace Displacements of the Control and the SC, MC, and MW Work Conditions, and between Control and Other Rest Periods.

rest averages of the level of BP trace for all experimental conditions are not significantly different from the control rest level. This is also true of the postrest average level following the MC work condition. The average level of the BP trace during the postrest periods of the MW and SC conditions is significantly higher than the control rest level.

Since the measurements of the actual blood pressure changes in the present study are relative, and in view of the method used to express these changes, a statement of percentage of change from a control level is improper and meaningless. We are warranted in saying, however, that mental work of the type engaged in and for the period studied does result in a definite increase in blood pressure, an increase distinct from the changes (a drop) in pressure resulting from tapping the psychergometer keys in the MC condition, or "sensing" the serial presentation of colors in the SC condition. The work of Darling and Darrow (8) suggests that during the mental work condition the autonomic balance was dominated by sympathetic innervation, while during rest, by parasympathetic innervation. During the MC and SC conditions, the balance seems to be in favor of parasympathetic innervation.

D. Skin Conductance Level

The skin conductance level was noted continuously throughout the entire session for all conditions and phases of conditions, but was recorded photographically only during those periods already reported for the other physiological responses. The conductance level was measured directly from the calibrated bromide record in terms of units of log. micromhos $\times$ 100. Table 9 presents the essential data for the group. The mean and SE_m of conductance level per 15 seconds for each record period for each experimental condition of MW, MC, and SC, and control rest are tabulated in Table 9.

The trends in the conductance level during the 55 minutes of work of the MW, MC, and SC experimental conditions and during control rest are graphed in Fig. 8 by plotting the average conductance level of each succeeding 5-minute record period. All conditions result in a gradual decrease in skin conductance. The greatest reduction in conductance occurs during the first 15 minutes of control rest after which the trends tend to parallel the trends in the other conditions. The test of difference between the first and second thirds of the control curve indicates a significant difference

TABLE 9

MEAN (m) AND SE_m OF MEASUREMENTS OF LOG. MICROMHOS × 100 PER 15 SECONDS FOR EACH RECORD PERIOD OF THE EXPERIMENTAL AND CONTROL CONDITIONS

Condition	Prerest 10 min.	Work Period 55 Minutes						Postrest 10 min.	Total Work	Total Rest
		1–5	11–15	21–25	31–35	41–45	51–55			
MW										
m	144.738	151.068	148.988	148.638	147.150	145.02	144.144	139.734	147.492	142.44
SE_m	.602	.874	.844	.867	.857	.875	.863	.646	.344	.442
MC										
m	145.644	144.833	140.983	139.2	138.550	136.264	136.416	135.630	139.429	140.741
SE_m	1.081	1.356	1.362	1.362	1.359	1.469	1.359	1.080	.566	.773
SC										
m	149.687	146.650	142.375	143.369	141.125	141.120	140.718	132.439	142.504	141.597
SE_m	.994	1.398	1.506	1.381	1.448	1.165	1.558	1.014	.601	.766
Control										
m		138.144	131.021	129.430	128.791	126.913	127.881		130.391	
SE_m		1.331	1.296	1.272	1.189	1.244	1.284		.528	

with greater than 1 per cent confidence. The test between the second and third thirds suggests that the trend of conductance is definitely leveling off; the difference between these thirds is insignificant.

There was a strong tendency to sleep during the control rest condition. This tendency was resisted by the attitude of each subject to cooperate as best he could in maintaining a wakeful state of "mental repose." In healthy subjects the skin conductance decreases considerably during sleep. Conductance levels equal to 90 to 100 log. units (125,000 to 130,000 ohms resistance) were not unusual for those subjects who actually slept during the control rest days early in the experimental program. These control records were not used. Most of the subjects did sleep during the last fifteen minutes of control rest; at least, their condition could be called near-sleep. But despite their proneness to sleep, or actual sleep, the conductance level did not descend to the usual sleep conductance level. Perhaps the maintained level is representative of a certain degree of alertness and tension which the subjects continued to express in response to the control condition instructions even though they nearly slept.

The rough tests of trend changes in conductance level during mental work (MW) indicate a reliable decrement from third to third; at least, a 5 per cent confidence inheres in the difference between the succeeding thirds.

Table 10 presents the critical ratio tests of significance of difference between the work period and the pre- and postrest periods within each experimental condition for the palmar skin conductance. The differences are expressed in terms of log. conductance (micromhos × 100) units. The 55 minutes of mental

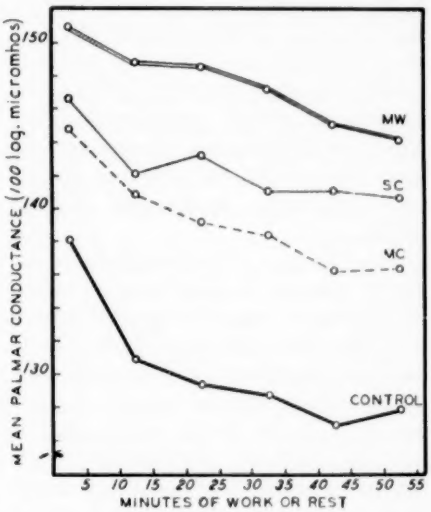

FIG. 8. Trends in the Average Palmar Skin Conductance per 15 Seconds for Successive Record Periods during the MW, SC, MC Work, and Control Rest Conditions.

TABLE 10

CR TESTS OF SIGNIFICANCE OF DIFFERENCE BETWEEN THE REST PERIODS AND THE WORK PERIOD WITHIN EACH EXPERIMENTAL CONDITION FOR PALMAR CONDUCTANCE

(LOG. MICROMHOS × 100 UNITS)

Rest Period	Work Period of Condition		
	MW	MC	SC
Prerest			
$M_{diff.}$	2.754	6.215	7.093
CR	3.98	5.09*	6.09*
Postrest			
$M_{diff.}$	7.758	3.80	10.156
CR	10.61	3.14	8.53
Total rest			
$M_{diff.}$	5.052	1.312	.997
CR	9.04	1.37	1.02

* Difference is in favor of the rest period.

work (MW) resulted in a significantly higher average conductance level than the average conductance level in either the prerest or postrest of the MW condition. This is not true for the MC and SC conditions. In both of these conditions the average level of conductance during the prerest period is significantly higher than the average level of conductance during their respective work periods. As shown in Table 9 the trend of the average level of conductance for both the MC and SC conditions decreases from the prerest level, throughout the work periods (Fig. 8), to the lowest level of conductance during the postrest period.

The average levels of conductance for the 55 minutes of work for each of the experimental conditions are significantly different. The differences have already been noted in Fig. 8. If palmar skin conductance is an indirect measure of alertness (11, 12) and bodily tension (18) it may be noted that color-naming work required a greater degree of alertness and general bodily tension than mere passive perception of serially presented colors and mere responding by pressing keys at a voluntarily controlled rate while blindfolded. Similarly, the passive perception demanded greater alertness and tension than the key-tapping condition.

The conductance levels of the rest and work periods of the experimental conditions are higher than the control rest level. The differences and their tests of significance are noted in Table 11 where it can be seen that the only exception to a significant difference is the postrest of SC and control. These differences between control rest as a base and the work and rest periods of the experimental conditions are diagrammed in Fig. 9.

The conductance level during prerest is probably determined by the adjustment which the subject makes to the anticipated task. The conductance level represents the tension of set expectancy. The conductance levels of the prerest periods of MC and MW are essentially equal but the SC prerest level is reliably higher than the MC and MW prerest levels. The conductance level of the postrest periods is a function of the previous task. Greatest relative reduction of conductance is made after the work of sensing or gazing at the serially presented colors of the psychergometer.

The results justify the conclusions that light homogeneous mental work—manual discrimination of randomly and serially presented colors—is accompanied by an initial increase in skin conductance from a prerest level of conductance. The average initial increase in skin conductance during the first five minutes of the mental work is about 6 log. micromhos × 100 units greater than the average skin conductance obtained during a ten-minute prerest period. The average level of skin conductance during 55 minutes of manual color naming is about 17 log. micromhos × 100 units greater than the average level of skin conductance during a comparable period of mental repose. Similarly the task of key tapping resulted in an average increase in skin conductance of about 9 log. conductance units,

TABLE 11

MEAN$_{diff.}$ AND CR TESTS OF SIGNIFICANCE OF DIFFERENCE BETWEEN THE CONTROL CONDITION AND EACH PERIOD OF EACH EXPERIMENTAL CONDITION FOR PALMAR CONDUCTANCE (LOG. MICROMHOS × 100 UNITS)*

Period	CR Test between Control and Experimental Condition		
	MW	MC	SC
Prerest			
$M_{diff.}$	6.594	7.500	11.543
CR	4.51	4.38	6.95
Postrest			
$M_{diff.}$	9.343	5.239	2.047
CR	11.20	4.36	1.81
Total rest			
$M_{diff.}$	12.049	10.349	11.206
CR	17.51	11.05	12.04
Work			
$M_{diff.}$	17.101	9.038	12.203
CR	27.1	11.6	15.2

* All differences are in favor of the experimental conditions.

and the task of mere gazing at serially presented colors resulted in an increase of about 12 log. conductance units above the average skin conductance obtained during a comparable period of mental repose.

The Centralist Position

If it is assumed that the mental activity of color naming, as represented in the MW condition, can be fractionated into motor, sensory, and central components, and that the noncentral components can be subtracted out in order to determine the dynamics of "pure" mental activity, then it may be reasoned (as implied in the centralist position of Benedict and Benedict [2]) that some measure of the energy of mental activity involved in the MW condition may be obtained by suitably subtracting out the energy needed in the expression of the MC and SC conditions. It must be further assumed that the MC and SC conditions exercised completely and exclusively the motor and sensory components, respectively.

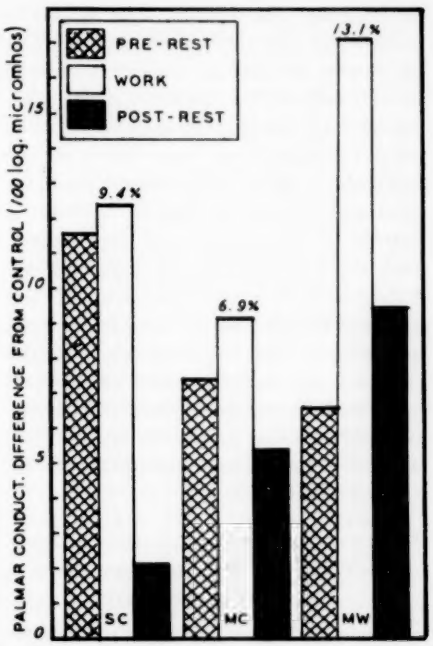

FIG. 9. Differences between the Average Palmar Conductance Levels (Log. Micromhos × 100) of Control and the SC, MC, and MW Work Conditions, and between Control and Other Rest Periods.

Of the various physiological reactions observed, heart beat and respiration rates are the best indices of total metabolism. Following through the procedure, summing the differences between control and MC and SC conditions, and subtracting that sum from the difference between the MW and control conditions, we obtain the following "residues" for respiration (Table 3) and heart beat (Table 6): 0.128 respiration and 1.056 heart beats per 15 seconds. If the centralist hypothesis of "pure" mental work and the assumptions are correct, then it might be concluded that the light, homogeneous mental work, the work performed (presumably) by the central factor, required a little more than a half respiration and four

heart beats per minute. The Benedicts concluded that their 4 per cent increase in rate of metabolism for rather difficult work could not be due solely to the activity of the brain cells (as they hoped to be able to show), but most likely to the muscular activity of increased heart action and ventilation. But if the data reported in the present study are correct, and the assumptions and reasoning are valid, then it might be concluded that the half respiration and four heart beats per minute are required for both the cerebral metabolic activity *for* mental work and the supporting secondary physiological activities (respiratory and cardiac activities themselves included) of the cerebral activity.

E. Relation between Changes in Mental Work Products and Changes in Physiological Activity

The question now arises as to the relationship between the *changes* in the several physiological activities and the mental work product *changes*. The group results indicate that mental work produces significant increases in heart beat and respiration rate, blood pressure, and skin conductance.

Since each subject's results were treated in the same manner reported for the group, data are available for correlating the physiological activities measured with the mental work products. The average level of the physiological activities for each five-minute record—six such alternate five-minute record periods in the 55 minutes of mental work—were ranked and related to the ranked mental work products of average responses and average blocks for each five-minute record period. Eight rank-difference correlations were obtained for the results of each mental work day for each subject, 320 in all. The individual correlations themselves demand a very high value, 4 degrees of freedom with only 6 pairs of measurements, to be regarded as significant. But the combining of four correlations, four days for each subject, and the combining of these for all subjects reduce the magnitude of the value demanding significance. The combined correlations provide information on the presence and direction of an existing relationship between some physiological activity and mental work. We are not aware of any reported correlations between the same physiological activities and mental activities made from *coincident measurements* and therefore have no basis for comparing the magnitude of correlations obtained in the present study with others. However, it might be noted that Darrow and Heath (13) obtained correlations of the order of .30 between similar physiological activities in response to discrete stimuli and certain personality factors as measured by the questionnaire technique. Wenger (30) obtained correlations of the order of .25 between some similar physiological activities and rate of recitation, speech, counting, tapping, and tonguing.

The Spearman method of rank-difference correlation was used. First-place rank was given to that measurement having the greatest numerical magnitude in each set of six measurements of each of the two variables correlated. No correction was made for trend.

In combining the correlations for the four MW days the z transformation was used. The z transformation was also used to obtain the combined correlation for all subjects. No correction was made for similar rank values. The rho's were not translated into Pearsonian r's.

Table 12 presents the combined rho's

TABLE 12

COMBINED CORRELATIONS OF FOUR DAYS OF MENTAL WORK FOR EACH SUBJECT ($df = 12$) AND FOR ALL SUBJECTS ($df = 30$) BETWEEN THE CHANGING MEANS OF THE WORK PRODUCTS AND THE CHANGING MEANS OF THE VARIOUS PHYSIOLOGICAL RESPONSES

Measurements Related	Subjects										Group
	Da	Gi	Gu	Ha	Le	Me	Ro	To	Wa	Wh	
Responses—Respira.	.58	.43	.65	.81	.33	.81	.59	.71	.54	.47	.62
Responses—Heart B.	.33	−.50	.86	.09	.02	.64	.69	.76	.19	.53	.43
Responses—Blood P.	−.05	−.28	.19	.25	.05	−.07	−.32	−.27	.07	−.51	−.08
Responses—Log. Cond.	.34	.77	−.09	−.04	−.03	.76	.47	.64	.32	.14	.39
Blocks—Respiration	−.41	−.13	−.57	−.55	−.46	−.57	−.39	−.32	−.92	−.58	−.54
Blocks—Heart Beat	.20	.10	−.77	−.09	−.19	−.55	−.26	−.94	−.66	−.35	−.46
Blocks—Blood Pres.	.27	−.06	−.08	−.19	.34	−.14	.21	.23	−.12	.08	.02
Blocks—Log. Cond.	−.38	−.76	−.41	.36	−.21	−.41	−.47	−.97	−.93	−.53	−.60

for each subject for each of the eight correlations for the combined four days of mental work. Each combined correlation for each subject has 12 degrees of freedom. The standard error of z for 12 df is $1/\sqrt{12} = .288$. Thus significance at the 5 per cent and 1 per cent levels would require correlations of .51 and .63, respectively. Many of the correlations approximate these levels of significance.

Table 12 also presents in the last column the combined rho's for the ten subjects. These combined correlations have 30 df on the assumption that the physiological and mental work activities of each of the ten subjects are independent random samples of the same population of such activities in human behavior. The 120 df which the combining of 40 correlations would warrant is not justified in the present combination of "four subject days" with "subjects," so the more rigorous 30 df was imposed to satisfy partially our somewhat questionable practice of combining 40 correlations. Realizing the initial source of the rho's (six pairs of measurements), the nature of the averages that are correlated, and the larger sampling error of z for rho values, we are not intending to extract precision of measured relationship; we merely wish to indicate the possible presence of relation and its direction. The 30 df provide a SE_z of .1825 which roughly suggests 5 per cent and 1 per cent confidence in rho values of the magnitude of .35 and .45, respectively.

In Table 12 the correlations between the means of the work products and the physiological responses show considerable consistency of direction from subject to subject. Of the eight combined correlations for the group, two are zero in value: the relationships between the means of relative blood pressure trace displacements and responses, and between blocks. Since the measurement of relative blood pressure is questionable, these values are to be expected.

The obtained combined correlations of .62 for respirations and responses and −.54 for respirations and blocks suggest that these work products are a function of the changing organization of the momentarily mobilized energy which is indirectly expressed through respiration, and the adjustment made by the subject to the present work situation. It may be that the increasing blocking and decreasing response rate are a function of the subject's inability to maintain the initially higher energy mobilization, which in turn may be a function of another correlate of the total alignments of the body in the performance of the simple mental work task. This correlate may be general body tension with its related changes in skin conductance. Tension is

known to increase at the onset of work and to be maintained or even increased for a time, dependent upon the task set, and then to decrease to a level somewhat above that of rest (7, 15). Thus, the mental work changes may be due to the reduced respiration rate, which may produce a "relative" anoxia in the neuromuscular mechanism which is already taxed by repeated excitation; or another correlate (not known) may effect tension changes during the mental work which in turn may reduce the energy demands of the body and thus effect a reduction in respiration and also reduce the essential proprioceptive afferent excitation of the cortex (and the wakefulness center), resulting in lower mental work efficiency (and tendency to sleep).

Heart beat rate changes are likewise significantly related to the mental work products, as indicated by combined rho's .43 and −.46 for the changes in responses and blocks respectively. As the mean rate of color naming decreases and the mean incidence of blocks increases, the heart beat rate mean decreases during the mental work period. As with respiration, heart beat rate is an indirect index of total metabolic activity. Thus as the performance output of the practiced subject decreased during the working hour, the momentary energy mobilization likewise decreased. What has been said concerning respiration may be equally applied to the heart beat rate relationships.

The combined correlation of .39 between log. conductance of the skin and rate of color naming is significant at about the 3 per cent level. Since palmar skin conductance is an indirect measure of the level of alertness or apprehension of the subject, it may be said that as alertness decreases the rate of response decreases. Likewise, since conductance level is directly related to the amount of general body tension or tonus, it may be said that as general body tension decreases there occurs a decrease in the rate of color naming. Similarly, since the measurement of the skin conductance level is an indirect (and more reliable) index of varying metabolic activity (17), then as the momentary requirements of energy decrease, the rate of color naming decreases during the work hour.

The combined correlation of −.60 between average number of blocks and the average level of skin conductance is significant beyond the 1 per cent confidence level. The correlation implies that as the average number of blocks per record period increases, the palmar skin conductance decreases. Likewise, as the incidence of blocking increases the general bodily tension, mental alertness, and momentary energy requirements decrease, as measured indirectly by the skin conductance level decreases.

Skin conductance changes are a function of changes in the excitation background and susceptibility of the subject to stimulation. Stimulation results in momentary increases in conductance (GSR's) which recovers to the initial conductance level in varying amounts in about 15 seconds. The degree of recovery is a function of the altered excitation background as a result of stimulation. As will be pointed out later, blocks are associated with galvanic skin responses, and the number of GSR's decreases as the mental work throughout the hour continues. The general conductance level is less disturbed as the work hour progresses and tends to diminish. As the number of blocks increases, the number of GSR's decreases. With diminishing alertness, reduction in supporting tonus, the effectiveness of the individual color stimulus is reduced and tends less and less to result in momentary increases in skin conduct-

ance. Even the blocks cause fewer GSR's, as will be shown. This is Robinson's fifth principle of work decrement in operation (24). Robinson maintains that the work decrement of a given response mechanism is a function of the "qualitative integrity of the stimulus throughout the work period" during which changes in efficiency develop. The qualitative integrity of the colors is a function not merely of the practiced response of pressing the correct key, but of the entire adjustment which the worker makes to the total work situation and task. Changes within the worker, the work situation, and the action of work upon itself result in changes in the qualitative integrity of each of the five colors in eliciting the correct response.

All the physiological activities observed are related to the energy requirements of the mentally working subjects. In terms of the measured changes in respiration, heart beat, and skin conductance, the momentary energy requirements change during the mental work performance. The changing rate of respiration and heart beat (and relative blood pressure changes) are indicative of regulative changes in the circulatory system. The changes in skin conductance, rate of color naming, and incidence of mental blocking are indicative of changes in the neuromuscular system. The various correlations obtained are indicative of the integration existing between the two systems. The syndrome of physiological activities is a picture of progressive adjustment, of changes of internal regulation with respect to the mental work task and task effects upon the working organism.

F. Relation between Blocks and the Galvanic Skin Response

As blocking increases during the course of an hour of continuous simple homogeneous mental work, rate of respiration, heart beat, and palmar skin conductance decrease, while relative blood pressure tends to increase. All of these changing physiological activities are occasioned at levels greater than a resting level. The relationship between blocks and galvanic skin responses has already been suggested. A color-naming blocked response is characterized by a latency of at least twice the median reaction time of responses occurring within the immediate minute. This is in agreement with Bills' interpretation (3).

Figure 10 presents the plots of the number of blocks and galvanic skin responses occurring per minute for each of the six alternate five-minute record periods of the 55 minutes of color-naming work for the group. Almost a 100 per cent increase occurs in block incidence during the work period. The number of

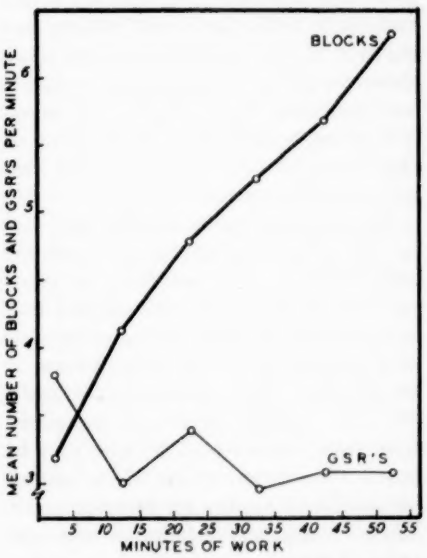

Fig. 10. Changing Average Number of Blocks and GSR's per Minute during Color-Naming Work.

GSR's per minute tends to decrease slightly during the course of the work; the decrease amounts to about 18 per cent. The last half of the mental work period shows practically no change in number of GSR's. These changes in the frequency of blocks and GSR's during the mental work must be considered in relation to the processes of block and GSR association. An attempt is made here to approach the problem of causal relationship in terms of "coincidence." The temporal definition of coincidence as here used places the problem on a broad basis. Later, an attempt will be made to describe the "causal" relation between blocks and GSR's more specifically.

The graphs of Fig. 11 describe the relationship between the blocks and GSR's in terms of the percentage of coincidence between the two phenomena. To understand further the plots of coincidence it must be recognized that there are different numbers of GSR's and blocks, and that several blocks may coincide with a single GSR, and more than one galvanic response may coincide with one long block. Thus it was necessary to make more than one notation of the degree of coincidence of block and galvanic phenomena.

Figure 11 shows the relative *decrease* in the percentage of *blocks associated with GSR's*, a decrease from 62 to 52 per cent from the first to the last five-minute record periods. However, in view of the considerable absolute increase in the number of blocks during work, the absolute number of blocks associated with GSR's increases. The same may be noted with respect to the blocks *not* associated with GSR's: an increase in absolute number and relative number (inverse of the curve of blocks with GSR's, Fig. 11).

While the absolute number of GSR's

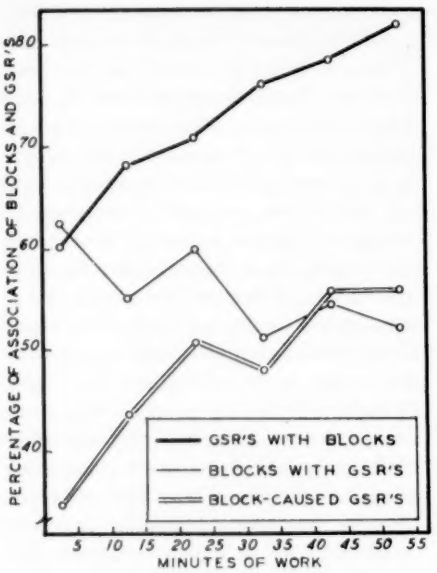

FIG. 11. Changing Percentages of Associations of Blocks and GSR's, and GSR's "Caused" by Blocks during Color-Naming Work.

decreases (Fig. 10), the percentage of *GSR's with blocks* increases (Fig. 11). The relative increase is from 61 to 82 per cent from the first to the last five-minute record periods. The GSR's not associated with blocks behave the opposite. As work progresses there are more and more blocks occurring which are *not* associated with GSR's, while the fewer occurring GSR's are becoming increasingly associated with blocks. This apparently contradictory relation becomes clearer if we assume that there are at least two types of blocks: galvanic and nongalvanic, i.e., one type of block accompanied by greater parasympathetic activity and another type not resulting in or accompanied by increased parasympathetic activation. At the same time, the GSR's are becoming decreasingly associated with spurts in work rate, i.e., momentary speeding up in color naming. Thus as the hour of mental

work continues, the GSR is occurring more frequently with inefficient responding and less frequently with efficient responding. There seems to be a shift in the pattern of color-naming responses in its demands on the parasympathetic system.

To discern more specific causality than mere coincidence between the block and the GSR, an examination was made to note the percentage of GSR's which are preceded by blocks within one to five seconds of the galvanic change. Specific causality is assumed on the basis of temporal relation. This examination revealed that 48 per cent of the GSR's are "caused" by blocks and that there is an increasing incidence of such "caused" GSR's as work progresses. This percentage was sufficiently high to indicate a causal relationship, for the GSR may be elicited by numerous other stimuli in the total mental work situation. Momentary increases in work rate, any considerable change in attention, atypical respirations, internal stimuli of various sorts—"mental" or physiological—extraneous laboratory stimuli may, and do, elicit GSR's. In three of the subjects, atypical respirations were responsible for a good percentage of GSR's. The evidence appears to be sufficient to say that most GSR's are caused by stimuli inherent in the mental work, primarily the block.

A question may be asked as to the nature of the blocks that are associated with GSR's and those that are not. Primarily the large blocks and "block groups" are associated with GSR's, while the occasional block does not result in a change in the conductance level. The GSR accompaniment of large blocks and block groups is the result of disturbance to the subject at a perceptual level. Subjects report they are vaguely aware of a "color" in the window of the psychergometer, and later recall it was red, but at the moment are unable to make a correct discrimination to press the correct key. They are forced to reorientate their attention to the color and the keyboard. Attention is shifted effortfully to the task by the work continuity set. The GSR is known to be elicited regularly by shifts in attention (10). If the shift is prolonged, or attitudinal, as a spurt in motivation, the general level of skin conductance is elevated to a new level of excitation background and work rate tends to be increased. It will be remembered that the general trend during mental work is toward a reduction in skin conductance, accompanied by a reduction in work rate. Thus as work progresses the blocks become relatively less and less the result of shifts in attention.

What is the nature of those blocks *not* associated with the GSR? The lesser or occasional blocks tend to be free of GSR association. Although they occur quite frequently in the early period of mental work they increase in frequency as work progresses. They seem to be "automatic" in their nature, i.e., the subject is unaware of their occurrence. The subject responds and continues with the task without any alteration in his effort, as though the block were a normal variation in color-naming behavior. This faltering in response may be due to faulty and inefficient operation of the implicit recognition process resulting from diminishing attention, and the result of competition among the response neural pathways. The general level of skin conductance diminishes and the incidence of GSR's decreases. The higher level of attention is accompanied by a higher level of conductance. The greater tension during the early periods of work may be a factor aiding the awareness and attention. As tension and attention diminish, the "auto-

matic" block becomes more frequent. The diminishing tension (decreasing conductance) throughout the color-naming work presumably removes the reinforcing support needed to maintain the directive set (attention, etc.), thus resulting in a loss of control and more blocks.

IV. SUMMARY AND CONCLUSIONS

A study of some of the physiological variables of mental work was conducted to obtain answers to three problems. (*a*) Do some internal physiological responses change significantly under conditions of light homogeneous mental work, and, if so, what is the nature of the changes? (*b*) Do the changes in some physiological responses show any degree of concomitance with the decrement in mental work production? (*c*) Are there any patterns of internal physiological responses related to mental work products?

The mental work task was color naming. Five colors were presented serially in random order by means of a Bills-type psychergometer (6). The colors were responded to manually at a rate determined by the practiced facility of each subject. Continuous records were made of the changes in rate of respiration and heart beat, relative blood pressure, finger volume, palmar skin conductance, and galvanic skin responses. These physiological and color-naming responses were photographically recorded by means of a Darrow-type photopolygraph (9).

Ten practiced, laboratory-adjusted, paid upper classmen and graduate students were used as subjects. For each subject there were designed four days of color naming by means of manual response, Days 1, 3, 6, and 10; two days of random tapping of the five color-naming keys, while blindfolded, at a rate judged by each subject to be his usual color-naming speed, Days 2 and 4; and two days of passively looking at the five random and serially presented colors at the rate of 90 per minute, Days 5 and 7. Each work period for all experimental conditions was 55 minutes long, preceded and followed by a ten-minute rest period. Each subject was exposed to two days of 55 minutes each of control rest consisting of a state of mental repose and relaxation. All the mental work days were at least two calendar days apart; in fact, most of the experimental sessions were at least two calendar days apart.

The three experimental conditions were designed to satisfy the historical demands of the "central theorists" (i.e., those who would segregate central nervous system activity from supporting metabolic or muscular activity). The keyboard-operating condition was presumed to elicit the motor component (MC), and the color-sensing condition the sensory component (SC) of the mental work condition (MW) of color naming by manual response. To satisfy the central theorists the MC and SC physiological effects were subtracted from the MW condition effects to obtain the residual effects due to the so-called central component. However, all the physiological effects of work of each experimental condition were compared to the effects of the control rest condition and the pre- and postrest periods.

1. The trends of changes in the rate of color naming and blocking are not due to chance but are due to factors present in the mental work operation and the organization of the mental worker.

2. The average rates of respiration and heart beat during color-naming work are significantly greater than the average rates during a control period of mental

repose or a period of rest before and after the work.

3. The average rates of respiration and heart beat are significantly greater during the mental work of color naming than during either the continuous work of random pressing of a psychergometer keyboard or gazing at serially presented colors.

4. Changes in rates of respiration and heart beat during the mental work probably represent momentary adjustments made to the demands of energy mobilization in response to the changing work situation.

5. A significant residue of a half of a respiration and about four heart beats per minute remains after subtracting those effects due to the so-called motor and sensory components of the mental work of color naming as represented in mere keyboard operating and mere "sensing" of serially presented colors.

6. Relative blood pressure significantly increases during color-naming work but significantly decreases during continuous keyboard-operating work and during continuous passive sensing of serially presented colors.

7. The level of palmar skin conductance is significantly greater during color-naming work than during a period of repose, or during a period of rest before and after the work, and greater than during continuous keyboard operating or continuous color sensing of serially presented colors.

8. The level of palmar conductance maintained during the different forms of work is related to the task difficulty, the degree of alertness, the amount of bodily tension, and the amount of energy mobilized to respond to the task situation.

9. A true control base line for physiological activities of minimal mental alertness is difficult to maintain for young adults for a period longer than ten minutes without the intrusion of sleep. All records of physiological responses of an hour of mental repose show a continuous slight decline for the first half hour before the true base line of physiological activity appears.

10. The changing rates of respiration and heart beat, and the changing level of palmar skin conductance during continuous color-naming work are positively correlated with the changing rate of color naming and negatively correlated with the changing frequency of blocking.

11. Changing physiological activities reflect changes in energy mobilization. As color-naming work output decreases, the amount of energy mobilized decreases. Mental work output is a function of the momentary mobilization of energy, the momentary and previous conditions of the circulatory and neuromuscular systems, and the momentary receptivity of the subject to further stimulation.

12. The changing association between galvanic skin responses and color-naming blocks indicates the existence of at least two types of blocks: galvanic and nongalvanic.

13. Galvanic blocks are large blocks or "block groups" which result from momentarily shifted attention and reduced alertness. The subject is quite aware of this block and is forced by the task pressure to reorient attention to the immediate stimulus.

14. The nongalvanic block is more automatic and spontaneous in its production. The subject responds as though the blocked response were a normal variation in color-naming reaction time. This type of block is more a function of response competition than is the galvanic block. As alertness diminishes, loss of control is evidenced by the increasing frequency of nongalvanic blocks.

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